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RESEARCH IN MILLIMETER WAVE TECHNIQUES

NASA GRANT NO. NSG-5012
GT/EES PROJECT NO. A-1642

R. E. Forsythe
Project Director/Principal Investigator

L. R. Dod
Project Monitor for NASA/GSFC

Report Period 15 July 1983 – 15 July 1984

August 1984

GEORGIA INSTITUTE OF TECHNOLOGY
A Unit of the University System of Georgia
Engineering Experiment Station
Atlanta, Georgia 30332

1984

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FOREWORD

This is the eighteenth and nineteenth semiannual status reports on NASA Grant NSG-5012. Due to reduced funding levels during this period, it has been necessary to combine these two reports. The grant period is from June 15, 1974 to June 30, 1985 and includes twelve extensions and increases to the scope and funding of the program. The total funding to date is $831,825 in NASA funds and $35,961 in Georgia Tech cost-sharing funds, for a total of $867,786. Current grant funding is at a level of $25,116.

Responsibility for technical effort on this grant lies in the Electromagnetics Laboratory, under the general supervision of R. G. Shackelford, Director. Mr. R. E. Forsythe has been the Principal Investigator of this program, which has the internal project number A-1642, since January 1979. Earlier principal investigators were Mr. J. W. Dees and Dr. R. W. McMillan. The program technical effort is divided between the Millimeter Wave Technology Division, responsible for source and mixer development, radiometric measurements, quasi-optical techniques, and analysis, and the Physical Sciences Division, responsible for mm-wave mixer diode development.

Contributors to the technical efforts and/or this report during the past six month period include: J. M. Cotton, D. O. Gallentine, R. W. McMillan, G. N. Hill, R. G. Shackelford, S. M. Halpern, D. Swank, R. A. Bohlander, J. J. Gallagher, A. Howard and Student Assistants: S. Shapiro and M. Leon. The assistance of G. Lamb at NASA/GSFC is also greatly appreciated.

1.0 Introduction

During the past twelve month period, the efforts on this program have been primarily devoted to:

1) Continued development of a reliable lower noise subharmonic mixer;
2) Continued development of a 183 GHz broadband, low noise quasi-optical RF-LO diplexer;
3) Investigations into IF interfaces of the three 183 GHz channels of the AMMS radiometer; and,
4) Support and evaluation of the AMMS RF and IF performance before and after data flights.

2.0 183 GHz Subharmonic Mixer Development

Work on the development of improved 183 GHz subharmonic mixers has been concentrated mainly in two areas. The first area is in improved performance of the currently available mixer body designs by assembling and testing various diodes from different sources and varying the whisker lengths. This work consists of assembling and reassembling the mixers and recording data until the best results are obtained. This is an ongoing task as upgrades in diode quality continue to take place.

The second area has been the completion of the design of a new improved body structure. This body has been designed so that the whisker and diode pins are in the same piece of the mixer that holds the substrate. This design helps reduce any relative motion of the parts that form the ohmic contacts of the diodes circuit. The body has not yet been built and tested due to lack of current funds. This design has been used with great success on a separate program at 90 and 140 GHz.

3.0 Quasi Optical RF-LO Diplexer

The broadband, low-loss, quasi optical RF-LO diplexer for use with a 183 GHz receiver has been developed and tested. A summary of its measured performance is given in Table I. This

TABLE I

183 GHz RF/LO Diplexer
Measured Performance

	LO Losses (dB)	RF Losses (dB)
Lens Loss	0.4	0.4
Polarization Splitter	0.05	0.1
Polarizer	0.4	0.4
Fabry Perot Filter	0.5	Varies See Below
TOTAL	1.35 dB	

RF Loss Summary

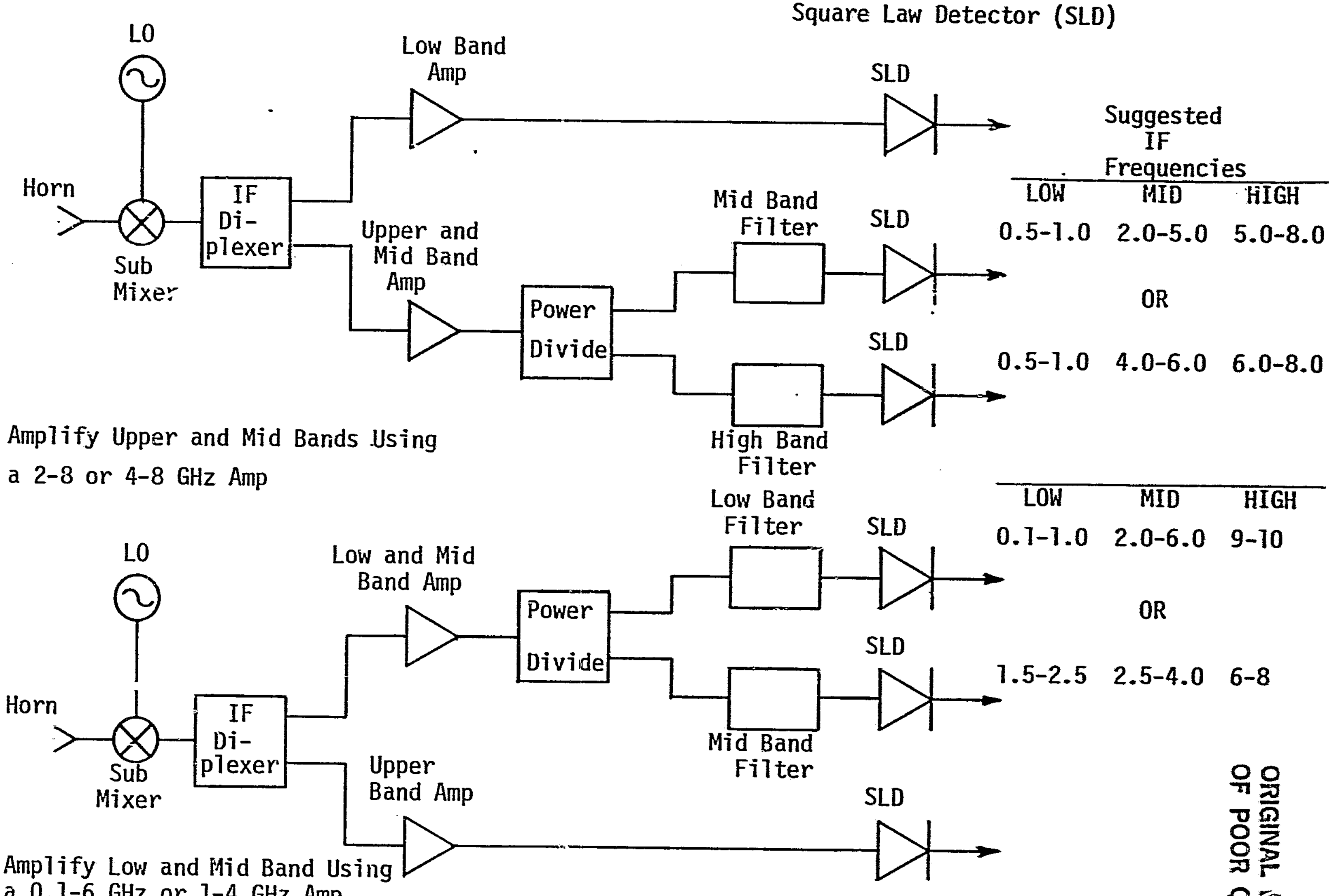
Frequency (GHz) |RF-LO|	Total Loss (dB) Including Fabry Perot
0.5	3.9
1.0	1.65
4.0	0.94
7.0	0.904

diplexer, which has been described in more detail in previous reports on this program, is designed for use with a very simple single ended mixer and uses a gaussian beam waveguide as its transmission medium.(1) The table shows the results of the individual devices and expected overall performance parameters. A proper beam waveguide system (horns and lenses), a low noise single ended mixer and a Gunn multiplier LO are needed to complete the development of a complete receiver system. The low amount of LO loss allows the use of a solid state local oscillator at 183 GHz. The main difference between this quasi optical LO-RF diplexer and other quasi optical diplexers is the use of the Fabry Perot parallel plate filter which reduces the number of nearby resonances and increases the instantaneous bandwidth of the receiver.

4.0 IF Interface Investigation of AMMS

The current AMMS IF frequencies and IF noise figure summary are given in Table II. The major problems that are present in this current configuration are the triplexer losses caused by the vendor missing the cutoff frequencies, cable losses due to cable length, and IF noise figures. A summary of some currently available IF amplifiers and their noise figures is given in Table III. Also included in this table is an improvement factor which indicates the improvement in overall minimum detectable temperature considering only the noise figure and bandwidth when compared to the current AMMS IF amplifiers. Simply divide the current AMMS sensitivity by the improvement factor to obtain the relative sensitivity (minimum detectable temperature) with these newer amps. The narrower band amplifiers have the advantage of reducing constraints on the IF multiplexer as well. This table is useful for comparing the state of art low noise IF amps for radiometric purposes.

One other option is to consider a diplexer and a broadband preamp followed by another diplexer as shown in Figure 1. A



(a) Amplify Upper and Mid Bands Using a 2-8 or 4-8 GHz Amp

(b) Amplify Low and Mid Band Using a 0.1-6 GHz or 1-4 GHz Amp

Figure 1. AMMS IF Configurations Using a Broadband IF Amplifier.

TABLE II

Current AMMS IF Noise
Figure Contributions

Noise Figure/Loss Source	Frequency (GHz) Low 1.5-3.0	Mid 4.0-6.0	High 7.5-10.0
IF Amp.	2.5 dB	3.2 dB	5.2 dB
Cable	0.8 dB	1.0 dB	1.9 dB
Triplexer	2.6 dB	2.0 dB	0.5 dB
Total	5.9 dB	6.2 dB	7.6 dB

TABLE III

Currently Available IF Amplifiers and Noise Figures

AMMS IFs

Low Band (from 0.5 to 3.0 GHz)
Mid Band (from 2 to 6 GHz)
High Band (from 6 to 10 GHz)

Band	Frequency (GHz)	Noise Figure (db)	Improvement Factor
Low Band*	0.7-1.2	1.0	0.81
	0.5-1.0	1.0	0.81
	1.0-1.5	1.0	0.81
	1.0-2.0	1.1	1.13
	0.5-2.0	2.0	1.12
	1.7-2.4	0.9	0.99
	0.8-2.4	2.0	0.91
	1.5-3.0	1.5	1.26
	1.5-2.0	0.8	0.85
Mid Band	2.0-4.0	2.0	1.32
	3.0-3.5	1.2	0.79
	3.7-4.2	1.06	0.82
	3.4-4.2	1.3	0.98
	2.0-6.0	3.5	1.32
	4.0-6.0	2.0	1.32
High Band	7.25-7.75	1.6	1.022
	8.5 -9.6	2.5	1.23
	9.0-10.0	1.8	1.38
Broadband**	4.0- 8.0	2.5	TBD
	0.1- 6.0	4.0	TBD
	2.0- 8.0	4.0	TBD
	4.0-12.0	4.5	TBD
	1.0- 4.0	3.0	TBD

*IFs at 1.09 GHz are difficult to realize in an aircraft due to interference.

**For use with a diplexer as described later; these allow use of broader IFs without multiplexing problems.

summary of suggested IF frequencies for these configurations is also given.

The desired IF frequencies for the 183 GHz portion of the AMSU radiometer are 0.75-1.25, 2.5-3.5 and 6.0-8.0 GHz. The AMSU is a multichannel radiometer system that will be flown in a satellite at a later date. The lowest channel is difficult, but not impossible, to realize in an aircraft environment because of transmitters such as IFF and TACAN at about 1.09 GHz. Careful shielding and filtering are required to eliminate interference. Another approach is to use a quasi-optical RF polarization diplexer and another receiver as shown in Figure 2. In the receiver used for mixing down the channel close to 183 GHz, the LO is offset so that higher IFs can be usd to mix down the desired frequencies. A high pass filter is also required to suppress the reception of the lower sideband in this receiver. The polarization splitter acts as a diplexer by allowing one linear polarization to pass while reflecting the other. This results in a very low loss RF multiplexer since only one polarization is received by each receiver anyway. Less than 0.05 dB loss in both RF paths (reflected and transmitted) has been measured using this quasi optical device. It consists of a set of fine metallic lines photolithographically etched on a very thin mylar sheet.

Any recommended approach of the choice of IF multiplexing/amplification depends on the tradeoff between overall sensitivity, cost, and desired similarities to the eventual AMSU IF and RF frequencies. Enough information has been gathered in this report to allow suitable recommendations to be made. Any changes in the AMMS IF system should also be accompanied with a relocation of the IF preamps to the RF baseplate to reduce IF cable losses. A summary of expected minimum detectable temperatures for some of the candidate receiver configurations described earlier are given in Table IV.

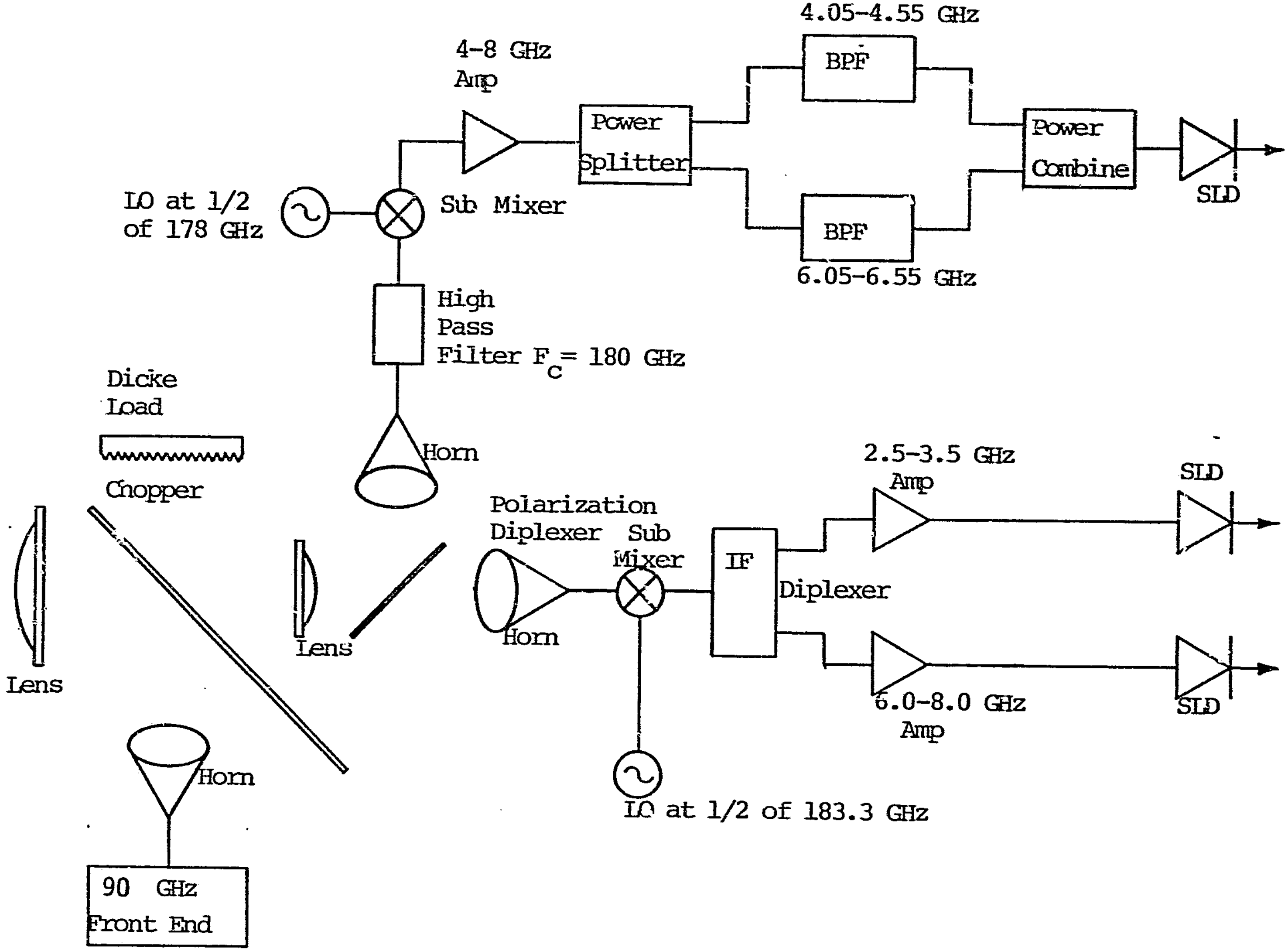


Figure 2. Offset LO Technique for Mixing RF Energy Close to 183 GHz (Avoids RFI)

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TABLE IV

Sensitivity Comparisons of Different Receiver Configurations*

Receiver Type	Minimum Detectable Temperature (K) Low	Mid	High
Figure 1(a) 2.0-8.0 GHz Amp	0.73	0.61	0.61
Figure 1(a) 4.0-8.0 GHz Amp	0.73	0.53	0.53
Figure 1(b) 0.1-6.0 GHz Amp	1.11	0.53	0.64
Figure 1(b) 1.0-4.0 GHz Amp	0.84	0.69	0.53
Figure 2	1.23	0.73	0.58
Triplexer w/0.5-1.0, 3.4-4.2, and 6-8 GHz IF Channels	0.79	0.67	0.56
Current AMMS with Triplexer and Cable Loss	1.19	1.1	1.37

*Assumes T_A = 290K, F_{RF} = 7 dB, 0.50 dB IF Diplexer loss, 0.75 dB High Pass Filter Loss (see Fig. 2). 0.4 dB, Lens loss (see Fig. 2), 0.75 dB Triplexer loss, and Integration Time of 60 msec.

From this table it can be seen that the best radiometer system can be realized using the system described earlier in Figure 1(a). 0.5-1.0 GHz, 4-6 GHz and 6-8 GHz IFs are used to obtain the best sensitivities. A diplexer separates the 0.5-1.0 and 4-8 GHz IF energy and this is followed by a broadband 4-8 GHz amplifier. This is also one of the easiest to realize in the current system.

The estimated relative performance of the system described from Figure 2 (shown earlier) is not as good and much more difficult to realize but has the advantage of being more closely related to the expected AMSU channels without the IF interference problems.

5.0 AMMS RF and IF Measurements

During this period some of the receivers developed on this program flew in the AMMS as part of a set of data flights in both the Convair 990 and ERII aircraft. The measured sensitivities of the 183 GHz channels were 2, 3, and 4K for the low, mid, and high bands respectively at a 0.06 second integration time. The LO frequency was measured to be one half of 183.3 or 91.65 GHz prior to these flights. After the flights the system had degraded considerably due to an LO failure. The frequency of the LO had shifted to 89 GHz and the output power had dropped. The LO is being evaluated to determine the problem.

6.0 Addition of a 118 GHz Radiometer to the AMMS

A technique for adding a 118 GHz channel to the existing AMMS radiometer system is shown in Figure 3. It uses the same polarization RF diplexing scheme as described earlier. The diplexer is broadband and operates anywhere from 30-300 GHz with low loss. Up to four RF front ends can be combined into the same lens using a super chopper and this diplexing approach. This diplexing approach is also ideal for diplexing two RF front ends

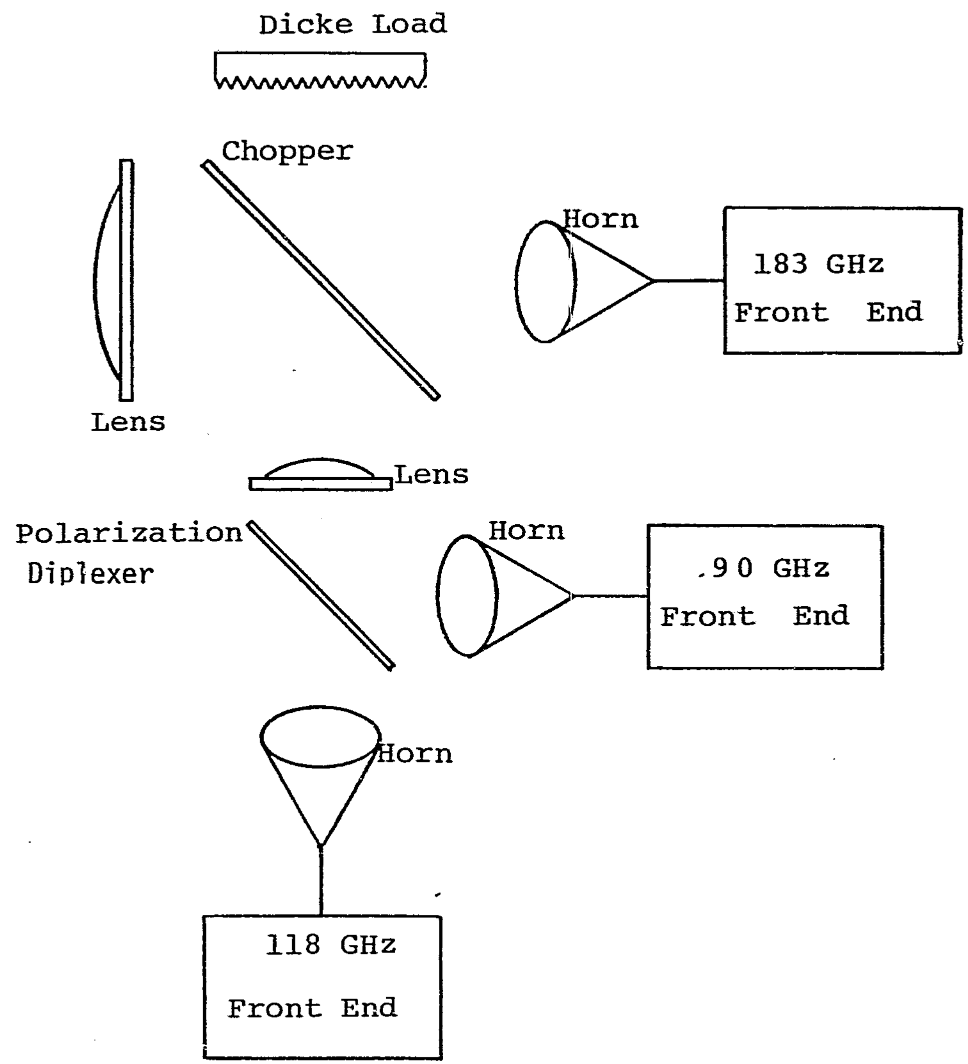

Figure 3. Addition of 118 GHz Radiometer to the AMMS Using Quasi Optical Polarization Diplexer.

in place of the super chopper if dc coupled total power radiometers are desired.(2)

Another technique would be to use WR-7 waveguide components and a single WR-7 wideband mixer. The cutoff frequency for WR-7 waveguide is about 91 GHz. Figure 4 shows a block diagram and frequency diagram for this receiver. The WR-7 waveguide is an effective high pass filter that allows single sideband reception of the 118 GHz energy. The appropriate RF channels are separated later in the IF to get data about this absorption line. This figure shows the frequency choices of the different LO, RF and IF frequencies that would be used in this receiver. The advantages of this receiver over the one previously described is primarily size and simplicity while noise figure would be much higher due to the broadband mixer and the high IF frequencies. A third technique would be to use a waveguide RF diplexer and narrowband receivers. A summary of the estimated noise figures for these approaches is given in Table V.

7.0 Plans for the Next Period

The plans for the next period are to continue the 183 GHz subharmonic mixer development, the 183 GHz quasi-optical receiver development, and begin work on a 183 GHz solid state local oscillator.

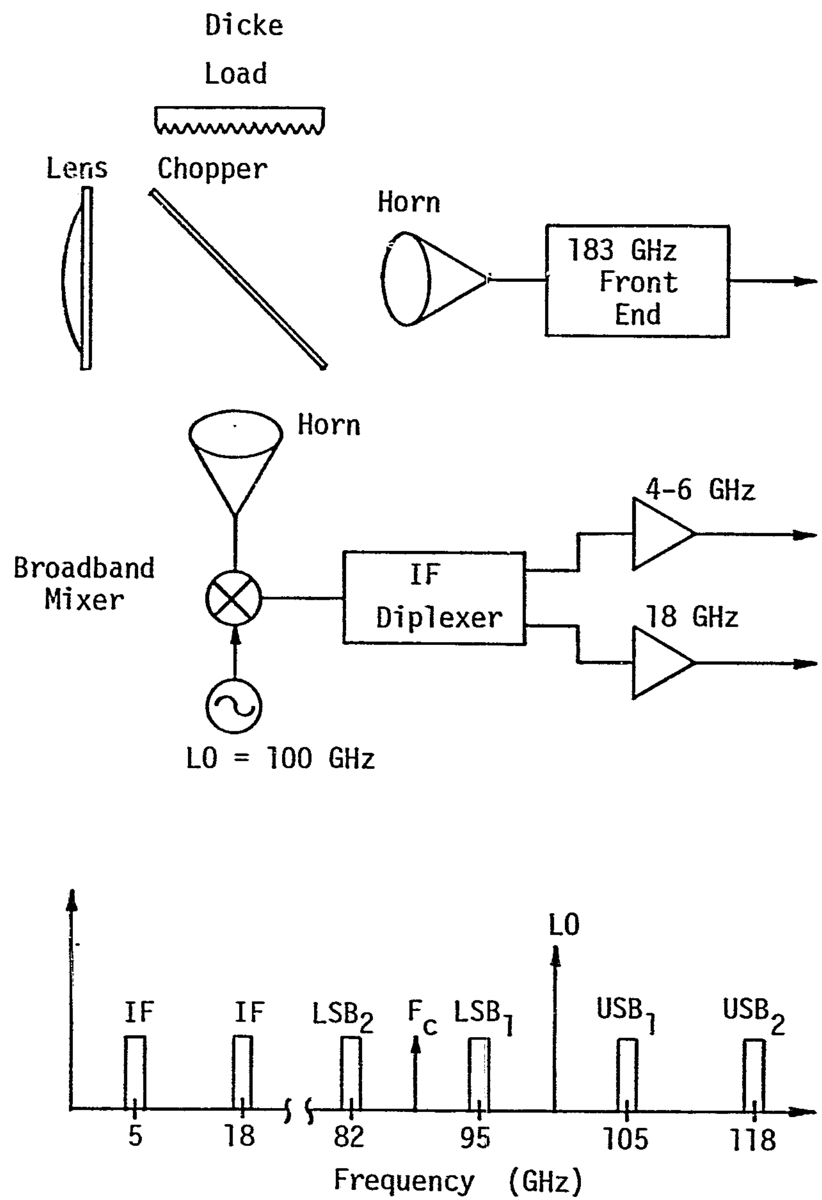

Figure 4. Broadband Mixer Approach for Adding a 118 GHz Radiometer to the AMMS.

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TABLE V

Comparison of 94 and 118 GHz
Noise Figures

Technique	Frequency 94 GHz	Frequency 118 GHz
Quasi Optical Diplexer Approach Noise Figure	6.0 dB	8.0 dB
Broadband Mixer Approach Noise Figure	10.0 dB	14.0 dB
Waveguide Diplexer Approach	7.5 dB	9.5 dB

References

1. "Research in Millimeter Wave Techniques", Semi-Annual Report, NASA/GSFC Contract NSG-5012, July 1983.

2. "A 140/220 GHz Radiometer for Airborne Imaging," IEEE International Symposium on IR and MM-Waves, Miami, December 1983.